Advanced Digital Smart Meter for Dynamic Billing, Tamper Detection and Consumer Awareness

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Abstract— **Developing countries are struggling to meet the electric power demands of fast expanding economies. Added to this is the poor infrastructure which has not kept pace with the increasing demand. Quality of supply too is gaining in importance. Poor metering and billing has rendered huge losses for utilities. Tampering and fraud is also rampant. Introducing Advanced Metering Infrastructure will go a long way in mitigating many of these problems. This paper details the development of Advanced Metering Infrastructure incorporating features to monitor supply parameters and perform functions like real time billing and alerts against overvoltage and overcurrent. The proposed meter is to utilize the capabilities of ADE7758 IC as well as microcontrollers such as ATMega16.**

Keywords- registers, interrupt, microcontroller, tampering, overvoltage, overcurrent

I. INTRODUCTION

An important aspect of development of futuristic smart grids is the development of advanced metering infrastructure. These meters will be digital in nature and will be able to measure important parameters like voltage, current and energy consumption. Perhaps the biggest change these meters will bring about is in the area of real time rate structures. These meters will occupy the same location as that of present day meters and will not have any direct design implications. From a design perspective, peak demand is a key driver. If peak demand per customer is reduced, feeders can be longer, voltages can be lower and wire sizes can be smaller [1]. One of the main problems utilities face in developing countries is the low level of billing and high tampering. These meters will be tamper proof and will help utilities increase their revenues by improved metering and fraud detection techniques. Electricity consumption usually peaks at predictable times of the day and the season. It is believed that billing customers by real time billing will force them to adjust their consumption patterns to be more responsive to market prices. Planning agencies hope these price signals will delay the need to build new power stations or at the very least reduce the amount of power that has to be bought from more expensive sources [2]. The biggest change that can be brought about by real time billing is that it will help in shifting consumption away from the peak hours to non peak hours thereby leading to improved asset management and eliminating load shedding. As a result the load curve can be flattened thereby eliminating the need for specialized generators to serve the needs of peak hours. Thus the existing generation capacity can be used to expand the connectivity in remote and rural areas with minimal investment.

This paper describes the development of Advanced Metering Infrastructure (AMI) with several features such as real time measurement of current, voltage and power apart from advanced features such as dynamic billing, over current and over voltage alerts. The meter will also be equipped with tamper detection techniques.

II. MOTIVATION AND PROBLEM DEFINITION

India loses money for every unit of electricity sold [11]. India has one of the weakest electric grids in the world. India requires massive investments in its power sector to keep up its impressive growth rates and also needs a modern intelligent grid. According to its Ministry of Power, India’s transmission and distribution losses are among the highest in the world, averaging 26% of total electricity production, with some states averaging as high as 62%. When non technical losses such as energy theft are included in the total, average losses are as high as 50%. The financial loss has been estimated at 1.5% of the national GDP, and is growing steadily. While the national government’s ambitious “Power for All” plan calls for the addition of over 1 TW of additional capacity by 2012, it faces the challenge of overcoming a history of poor power quality, capacity shortfalls and frequent blackouts [11]. Simply put, India cannot afford such colossal wastage of power. One of the best means to reduce theft, monitor power quality, improving metering and billing as well as bring about a sea change in consumer awareness is the introduction of advanced metering infrastructure. This will go a long way in reducing losses and help in better utilization of assets.

The challenge is to develop a meter capable of monitoring supply parameters, real time billing and giving alerts against overload conditions. The meter should also be capable of detecting tampering. Networking the meter is also envisioned to enhance its performance so that tampering may be reported to the utility. The meter should also be interactive allowing consumers to monitor their own consumption thus enhancing their awareness as well as encouraging them to shift consumption away from peak hours by introducing dynamic billing.

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III. RELATED WORKS

In [3], Seunghyun Park et. al details the development of a simulator for incorporating ‘power sockets’, devices which allows the consumer to monitor individual appliances in the household. It proposes to have many of these small smart meters to monitor individual appliances. In [5], development of a relay to balance the load on three phases based on a signal by smart meters is proposed. Papers [7] and [8] both propose comparing power drawn from the grid to sum of individual meter readings to detect tampering. Though [7] stops at this, [8] introduces a system whereby impedance of different parts of the grid is calculated by removing load and is matched with some pre calculated values to isolate the area of tampering. In [9] by Dirk Benyoucef et al, impact of smart metering on consumer awareness as well as how the data obtained as a result of smart metering is utilized by utilities to plan asset management is discussed. Paper [10] details the development of a hierarchy to give consumer control over how his appliances consume energy. It proposes a programmable controller which will consider the consumer’s need as well as pricing signals from the utility before switching on an appliance. This will allow the utility to take maximum advantage of intermittent sources like wind, solar etc while at the same time allow consumers to lower their energy costs and better manage assets.

IV. OVERVIEW OF THE PROPOSED METER

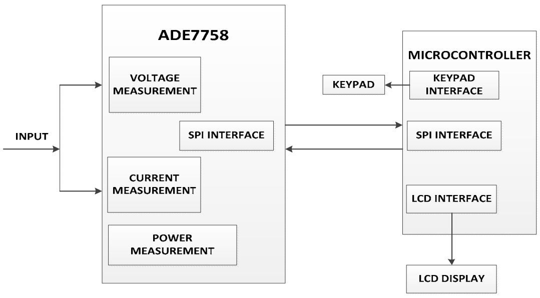

Figure 1.Overall functioning of the meter

The proposed meter works according to the hierarchy shown in Figure 1. The heart of the meter consists of an ADE7758 IC and an ATMega 16 microcontroller. The ADE7758 is an energy measurement IC. It is capable of measuring real, apparent and reactive energy for various Y and Delta three phase configurations apart from measuring rms voltage and current. All these parameters are stored in registers which are accessible by SPI serial interface. This IC also provides system calibration features for each phase, that is, rms offset correction, phase calibration, and power calibration [4].

The voltage, current and power measured by the ADE7758 IC are accessed by the microcontroller from their respective registers using serial interface and processed to implement features like real time billing, overvoltage and overcurrent protection etc. Keypad interfacing is done to enable consumers to monitor their consumption patterns as well as monitor quality of supply on an LCD display. An alarm system is also provided in case of detection of equipment fault or overcurrent and overvoltage.

V. MEASUREMENT OF VOLTAGE

As in Figure 2, for the measurement of voltage, we propose to use a series combination of 1MΩ and 1 kΩ resistors. The voltage drop across the 1 kilo Ohm resistor is to be fed to the input pin of the ADC. A 33nF capacitor which acts as a short for ac is also provided. As a result of voltage division, the bulk of the voltage will drop across the 1MΩ resistance while the drop across the 1kΩ resistor will be what is required for the operation of the ADE7758.

The ADE7758 needs to be configured to sample the waveforms by configuring wave select bits and phase select registers. Waveform samples of 24 bits are transferred one byte at a time with most significant byte transferred out first. Waveforms are passed through a low pass filter before rms voltage is measured. Voltage rms values are stored in rms registers.

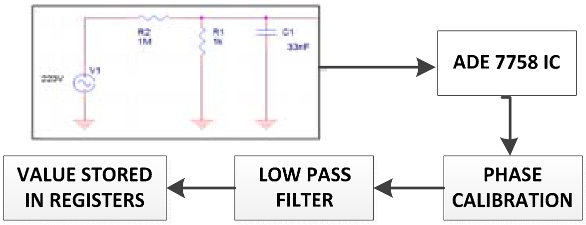

Figure 2.ADC and Signal Processing in Voltage Channel

VI. MEASUREMENT OF CURRENT

As shown in Figure 3, for the measurement of current, we make use of a current transformer with a burden resistor. A burden resistor connected across the secondary produces an output voltage proportional to the resistor value, based on the amount of current flowing through it.

Current transformers are devices used to scale large primary currents to a smaller, easy to measure, secondary currents. Like a traditional voltage transformer, the ratio of the windings determines the relation between the input and output currents. A CT is useful for measurements made on AC waveforms. It acts just like a regular voltage transformer, but typically has only one primary winding (the wire carrying the current to be measured). Unlike a regular voltage transformer, there is no physical connection made to the measured line. The CT uses magnetic fields generated by the AC current flowing through the primary wire to induce a secondary current. The ratio of the number of secondary turns to the number of primary turns determines the amplitude of the current on the output [5]. The output of a CT acts as a current source whose current output and burden resistor value is used to determine the voltage for ADC.

ADC has multipliers in signal path in the current channel for each phase. ADC also may have capabilities for calibration and gain adjustments. Whenever samples are available interrupt request output stays low. When this goes high, sampling is stopped. 24 bit waveform samples are transferred one byte at a time with most significant byte shifted out first. Current rms values are processed from these waveform samples.

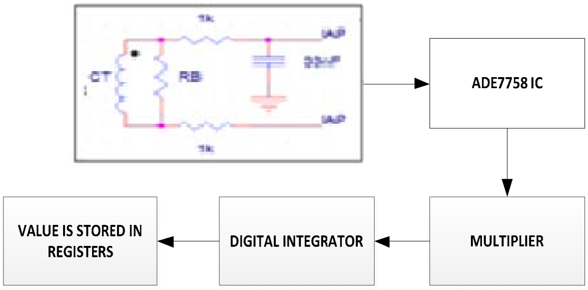

Figure 3.Current Channel Signal Path

VII. MEASUREMENT OF ACTIVE POWER

Electrical power is defined as the rate of energy flow from source to load.

$$v(t) = \sqrt{2} * Vrms * sin(\omega t) \tag{1}$$

$$i(t) = \sqrt{2} * Irms * sin(\omega t) \tag{2}$$

$$p(t) = Irms * Vrms - Vrms * Irms * \cos(2\omega t) \tag{3}$$

The average power over an integral number of line cycles n is given by the expression:

$$P = 1/nT \int_0^{nT} p(t)dt = Vr \tag{4}$$

t is the line cycle period. *P* is referred to as the active or real power. The instantaneous power signal *p*(*t*) is generated by multiplying the current and voltage signals in each phase. Average active power is obtained by passing power signal through a low pass filter which separates the dc component. Power is stored in separate registers. Ripples in signal may be removed when power is integrated over time to get energy. Active power is continuously accumulated in internal registers to get energy.

$$Energy = \int p(t)dt = \lim_{T \to 0} \{\sum_{n=0}^{\infty} p(nT)\} \tag{5}$$

Using serial interfacing, data (power) can be serially accessed from ADE7758 using microcontroller. That data is stored in flash memory. This is because power is measured in the interval of 5 minutes in order to achieve real time billing. So the microcontroller may not have the required memory to store the huge amount of data obtained. The output of the microcontroller is then displayed on an LCD display. Consumers can view the power consumed using a keypad. This helps customers understand their consumption patterns and if this data is transmitted it helps utilities in understanding load profiles of customers and better planning of resources [9].

VIII. ADVANCED FEATURES

The meter has many advanced features including real time billing,

A. *Real Time Billing*

Real time billing involves billing energy as it is used. It allows utilities to set different tariffs for different times in a day. As mentioned previously, readings are taken periodically and the billing is done simultaneously. This data is stored externally in a flash memory and can be retrieved by the consumer. The consumer can know precisely how much power he or she is consuming and at what times of the day his consumption is peaking. Billing takes place locally and in real time. The slab to be used for a particular time of the day is programmed by a representative from the utility on a monthly basis when he or she comes for collection of dues. It broadly follows the hierarchy shown in Figure 4.

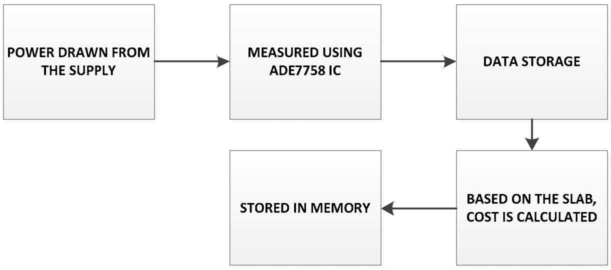

Figure 4.Block Diagram for Real Time Billing

B. *Tamper Detection*

For tamper detection, we can devise a simple wiring system. The four screws of the meter's frame should be shorted with a wire. When a person tries to tamper the meter, since the meter is a digital one, he has to open the meter frame to do any tampering. When the four screws are removed, the shorting is damaged and as a result, the 5V supply given to one of the input terminals of the microcontroller is cut off and the meter stops functioning.

C. *Overvoltage Protection*

The peak absolute value of the voltage waveform within a fixed number of half-line cycles is stored in a register by the ADE7758. The microcontroller accesses this value by serial interface and constantly compares this value with a preset value. If the measured value exceeds this preset value, an alert is given by the microcontroller.

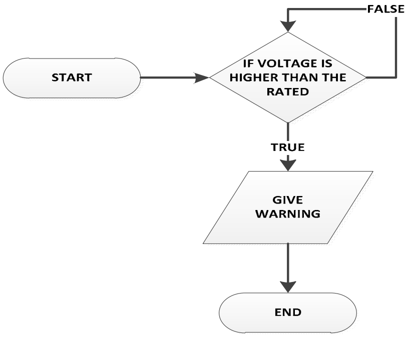

Figure 5.Flowchart for Overvoltage Detection

D. *Overcurrent Protection*

The peak absolute value of the current waveform within a fixed number of half-line cycles is stored in a register by the ADC. The microcontroller accesses this value by serial interface and constantly compares this value with a preset value. If the measured value exceeds this preset value, an alert is given by the microcontroller.

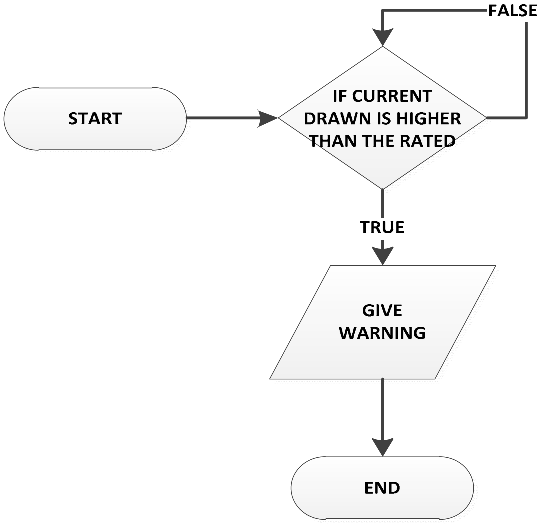

Figure 6.Flowchart for Overcurrent Detection

IX. EXPERIMENTAL RESULTS

A. *Interfacing LCD with ATMega16*

We interfaced LCD LM016L, a 16x2 LCD display with an ATMega 16 microcontroller. This LCD display is used to show various meter readings, real time billing information etc. to the consumer. Interfacing is done using 4 bit mode of LCD display function so that we can save 4 pins of microcontroller. The ADC IC will give the information about voltage, current, power etc. Microcontroller will process this information and will send this information to LCD display.

B. *Interfacing Keypad with ATMega16*

As shown in Figure 7, we interfaced a 4x4 keypad with ATMega 16 microcontroller. 8 pins of the microcontroller are dedicated for this keypad. Upper nibble of the port is set as input port and the remaining 4 pins are set as output pins. For checking if a key is pressed, output is continuously changed between 0 and 1 in 1 micro second interval. If any key is pressed, a particular number pattern is generated in the port. That number pattern is checked to find which key is pressed. Thus keys can be assigned to know the voltage, current etc. for the user.

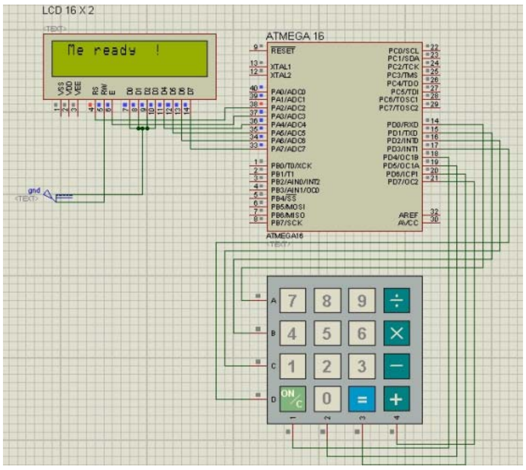

Figure 7.Proteus simulation of LCD and Keypad interfacing

C. *Load curve analysis of 20 houses*

TABLE I HOURLY POWER CONSUMPTION

TIME	BEFORE(WATTS)	AFTER(WATTS)
0-6	2100	2960
6-8	3400	2700
8-10	2000	2350
10-12	2700	2350
12-14	2850	2400
14-16	3100	2700
16-18	4100	3200
18-20	4150	3200
20-22	3200	3585
22-24	2700	3135

Above table shows the average hourly power consumption before and after the introduction of smart meter during different times of the day based on a survey of 20 houses. The anticipated shift in consumption can be clearly seen. More power is being seen to be consumed between 0-6 hrs as well as 20-22 hrs and 22-24 hrs. On the contrary the consumption during evening peak hours shows a marked decline as a result of higher prices. Consumers are seen taking advantage of the lower prices during the night hours for all non essential consumption.

Figure 8 shows the power consumption pattern of 20 domestic users for one day. Peak hour is the time when usage of power is very high. Normally it will be from 6:00 pm to 10:00 pm for predominantly residential areas. From the graph, it can be seen that usage of electricity peaks during this period. According to our real time billing concept cost per unit of electricity in this time range will be more than the normal and in the time periods when usage is very low (example during early morning hours), cost per unit can be made lesser than normal. This will encourage the consumer to consume less power during peak hours by shifting some consumption to non peak hours. Thus the concept of real time billing will in effect help in flattening the load characteristics which will in effect help users to save on energy costs as well as the utilities that are providing power to manage their assets better and expand services to more areas.

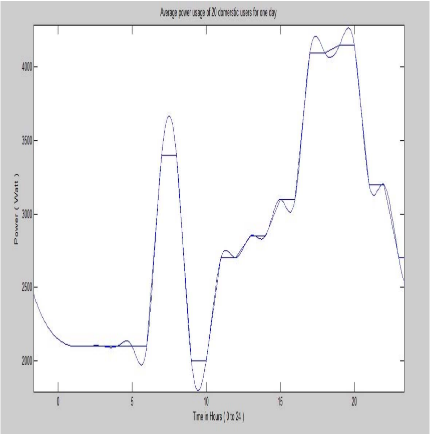

Figure 8.Load curve of 20 domestic consumers

An approximate graph estimate after real time billing is introduced in Figure 9. Here the load curve is more flat. Higher price during the peak hour will make user to shift the use of high load consuming appliances like AC, electric iron box etc. to non peak hours which ultimately help in flattening the load curve.

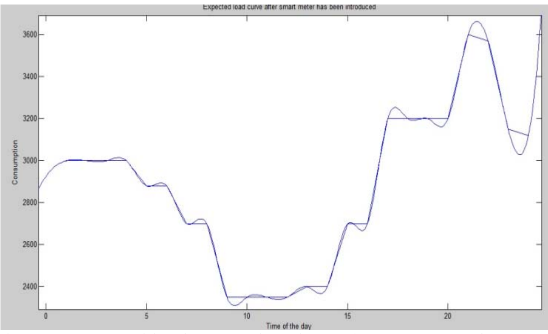

Figure 9.Expected load curve of 20 domestic consumers after smart metering is introduced

D. Over Power Consumption

When many appliances which consume high electric power are switched on simultaneously at a time, power consumption rate will be very high. If power usage of many consumers is similar, it may lead to a shortage on the supply side. To avoid power shortage, consumer is warned in the situations where power consumed is more than a rated value. This is done with the help of a microcontroller. Microcontroller continuously checks the power usage. If power consumption shoots up, alarm is given by blinking an LED .
[12]

X. CONCLUSION

In this paper, we have discussed the development of advanced metering infrastructure with features like real time billing, overvoltage and overcurrent protection, tamper detection. A survey showing shift in consumer behavior after implementation of real time billing was shown along with microcontroller interfacing with LCD and keypad.

XI. FUTURE SCOPE

Future work could focus on the development of the meter using development boards and using cost effective communication technologies like PLC to implement features like power sockets to monitor individual appliances within a household. Another idea could be to implement communication technology to automatically control relays to isolate parts of the grid requiring maintenance from the rest of the grid. These relays could also be used in balancing the load on three phases by switching consumers to get optimum performance from the grid [6].

XII. REFERENCES

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